THE ALIMENTARY TRACT OF PENTHE PIMELIA, FABR. (COLEOPTERA: DACNIDAE).[1]

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The insect studied, *Penthe pimelia*, Fabr.,[2] is a medium sized (12–14 mm.), broadly oval and depressed beetle of the family Dacnidae. It is gregarious in winter, and hibernates beneath the bark of old logs and old stumps in beech woods. The specimens used in this study were taken in a beech woods near Columbus. The first collection of beetles was preserved during October, 1931, in the following manner: The insects were killed by placing them in water and heating to a temperature of 70° C. (158° F.), then placed in fixing solutions. Half of them were fixed in Kahle's solution; the remainder in Bouin's solution. The mid-intestine was not preserved well enough to permit the cutting away of muscles, trachea, and fat body, without tearing it. The Malpighian tubules were also very brittle. Microscopic sections were made of various parts of the tracts of many different preserved specimens, but most of them were of no value because of the poorly preserved condition of the tissues. It was necessary to obtain live beetles in order to trace the Malpighian tubules in the gross anatomy studies, and to get better material for making microscopic sections.

Sections made from the alimentary tracts taken from live beetles proved to be satisfactory. The digestive juices of this insect act very quickly upon the epithelial lining of the stomach after it is killed, so the beetle was opened under normal saline solution, and when the tract was entirely uncovered, this solution was removed and the fixing agent (Kahle's Fixative, in this case) was put on. Thus the preserving solution reaches the tract and both kills and fixes the tissues before digestion of the stomach lining occurs.

With the exception of the first dozen or so slides made, all sections of the tract were cut at five microns. The usual method of double staining with Haemalum and Fast Green, FCF

[1]Melandryidae of some authors.

[2]The author wishes to express his appreciation for the helpful suggestions and criticisms of Dr. C. H. Kennedy, and for the aid given by Dr. D. M. DeLong in identifying the insect studied.

as described in the laboratory outline for the internal morphology course, was followed for practically all of the slides made. A few were stained with Delafield's Haematoxylin and Eosin. However, the tissues did not stain as well with the latter two, so their use was discontinued.

The drawings were made with the aid of a microprojector.

Gross Anatomy of the Digestive Tract.

GENERAL ANATOMY.

The alimentary canal of *Penthe pimelia* Fabr., is a simple tube extending from the mouth to the anus, with only one loop in its entire length. It is about one and one-half times as long as the insect's body. The three principal divisions—the fore-intestine, the mid-intestine, and the hind-intestine—are easily distinguished in this beetle (Plate I, Fig. 1).

The fore-intestine consists of the mouth, the pharynx, the oesophagus, and terminates at the oesophageal valve.

The mid-intestine is straight and of the same structure throughout its length. It begins at the oesophageal valve, and ends at the pyloric valve.

The hind-intestine begins at the pyloric valve. The Malpighian tubules, six in number, arise at this point. They appear singly and at regular intervals around the circumference of the valve. The ileum is considerably smaller than the stomach, being only about one-fourth the diameter. It goes back from the stomach, turns to the left, under the colon, goes forward into the first abdominal segment, then turns to the right again and goes back to the colon. The colon is somewhat larger than the ileum and a little more than half as long. The distal ends of the Malpighian tubules are attached to the colon by a sheath of connective tissue. The tubules are regularly spaced around the circumference of the colon, each one, however, following a much convoluted path to the caudal end of the colon. The rectum is slightly less than half as long as the colon, and connects the rest of the tract with the anal opening. It is a straight tube, smaller in diameter than the colon, but larger than the ileum.

The size of any part of the canal varies from these proportions when food is present in it.

GROSS STRUCTURE OF THE FORE-INTESTINE.

The fore-intestine is a short tube about one-fifth the length of the body, extending from the mouth back through the head to approximately the middle of the prothorax, where it joins the mid-intestine. It is composed of the pharynx, the oesophagus, the (crop), and terminates at the oesophageal valve.

The *pharynx* is the slightly wider part of the tube just back of the buccal opening. The *oesophagus* is the part of the tube connecting the pharynx to what may be the crop or may be merely a part of the oesophagus which is larger than the rest. This larger portion connects

with the mid-intestine at the *oesophageal valve*, which appears externally as a heavy ring of muscle.

GROSS STRUCTURE OF THE MID-INTESTINE.

The anterior end of the mid-intestine is marked by the muscular oesophageal valve. The mid-intestine varies in size, depending upon the amount of feeding the insect had done at the time it was killed. When full of food material, it is nearly cylindrical, perhaps a trifle larger at the posterior end than farther forward, and occupies about one-half the length of the body. The stomach of a beetle which has not been feeding prior to the time of examination is somewhat contracted, and may be only three-fifths as long as when full. The surface of the mid-intestine is covered with many small projections or crypts. These are of approximately the same size the entire length of the stomach. The posterior end of the mid-intestine is marked by the attachment of the Malpighian tubules and by the pyloric valve.

GROSS STRUCTURE OF THE HIND-INTESTINE.

The hind-intestine is approximately two-thirds as long as the body, and is distinctly differentiated into its various parts, that is: the pyloric valve, the Malpighian tubules, the ileum, the colon, and the rectum.

The *pyloric valve* is evident externally as a heavier walled portion of the canal at the posterior end of the stomach.

The *Malpighian tubules* are six in number and are attached to the canal at the pyloric valve. They are evenly distributed around the circumference of the tract. They are approximately twice as long as the beetle itself, and are much convoluted. The tubules begin at the pyloric valve, wind around in the body cavity in the region of the ileum, and one loop of each goes forward along the mid-intestine, then back to the colon, where it becomes encased in a sheath of connective tissue surrounding this part of the canal. The tubule becomes more or less flattened after it attaches to the colon, and pursues a zig-zag path caudad under this sheath to the point where the rectum begins, and there ends. All the Malpighian tubules are fastened to the colon by this layer of connective tissue or "peritoneum," and are regularly spaced around it. The tubules are colorless and very hard to distinguish for a short distance from the point of origin at the pyloric valve. They gradually become more yellow in color as the distance from the attachment increases. This coloration is pronounced for the last third of the length of the tubules, but disappears when they enter the sheath of tissue surrounding the colon, and for the remainder of their length they are colorless.

The *ileum* is a slender tube leading from the pyloric valve to the colon. As stated in the general discussion of the gross anatomy, the only loop in the main tract occurs in this part.

The *colon* is considerably larger in diameter than the ileum, nearly twice as large, and it is sheathed in a case of connective tissue which holds the Malpighian tubules tightly to it. It appears to be less muscular than the ileum.

The *rectum* is the short straight tube leading from the colon to the anus.

Histological Structure of the Digestive Tract.

HISTOLOGICAL STRUCTURE OF THE FORE-INTESTINE.

The fore-intestine has the same histological makeup throughout its various parts. The tissues present from within outwards are found in the following order Plate I, Fig. 2:

(1) Intima (or chitinous cuticula).
(2) Epithelial layer of cells (Hypodermis).
(3) Basement membrane.
(4) Longitudinal muscle.
(5) Circular muscle.

The innermost lining of the fore-intestine is the *chitinous cuticula* which is continuous with that of the outer body wall, and is secreted by the fore-gut epithelium. The intima is in wave-like folds, and its inner surface is more or less dentate up to the oesophageal valve. At the opening through the valve proper, the *intima* is smooth, and it remains so to where it meets the gastric epithelium.

The *hypodermis* is a layer of irregularly-shaped cells just beneath the intima, and parallels the convolutions of this layer. The *basement membrane* is not clearly shown.

The epithelium is surrounded by a well developed *layer of longitudinal muscles*. These follow the waves of convolutions of the intima to some extent and are more abundant inside of pronounced folds.

The *circular muscle layer* is also well developed. It is around the outside of the longitudinal muscles, and forms a sheath for the rest of the tissues.

Although the oesophagus increases in size as it approaches the oesophageal valve, the relative proportion of the different tissue layers remains the same. It is doubtful that this larger portion has any function other than conduction of food, as it is not large enough to be called a crop, nor heavily enough chitinized to be a gizzard.

The *oesophageal valve* is a fold of the fore-intestine which extends into the mid-intestine, then turns back on the outside of itself to meet the mid-intestine (Plate I, Fig. 3). This valve has four lobes in cross-section. The epithelial cells of the part which extends into the mid-intestine and folds back on itself becomes longer and narrower, finally appearing as a columnar epithelium before the fore-intestine meets the gastric epithelium. The valve is surrounded by a heavy band of circular muscles.

At this point the layers of muscle tissue change their relative position; the circular muscles, which were on the outside in the fore-intestine, are inside the longitudinal muscle layer in the mid-intestine.

HISTOLOGICAL STRUCTURE OF THE MID-INTESTINE.

A histological study of the mid-intestine shows it to be similar in structure throughout its entire length. There are five layers of tissue (Plate I, Fig. 4). Starting from the inside, they are:

(1) Peritrophic membrane.
(2) Epithelium of endodermal tissue.

(3) Basement membrane.
(4) Circular muscles.
(5) Longitudinal muscles.

The peritrophic membrane encloses the food material and protects the delicate epithelial cells from the rough particles.

The cells of the epithelial layer vary in structure or shape according to whether they are in the secretory or resting stage. Soon after the insect takes in food, the cells become distended and some of them break off to supply digestive fluids (holocrine secretion) (Plate I, Fig. 4). These cells are replaced by new cells formed by certain regenerative tissues contained in crypts (Plate I, Fig. 5). In the outer end of these crypts are the masses of regenerative tissue called nidi. Externally the crypts appear as papillae which cover the surface of the mid-intestine. They all have the same structure.

The circular muscles appear just outside the basement membrane of the gastric epithelium.

The longitudinal muscles, usually only a thin layer, occur outside the layer of circular muscles.

HISTOLOGICAL STRUCTURE OF THE HIND-INTESTINE.

The pyloric valve is formed by the extension of a fold of the hind-intestine into the lumen of the mid-intestine (Plate II, Fig. 7). This fold is composed of epithelial cells of the hind-intestine, but instead of being more or less cuboid in shape, they become elongated into narrow, closely packed columnar cells. These are lined on the inside with a layer of chitin armed with spines. These spines persist into the ileum for approximately one-seventh of its length.

The function of these spines is unknown to the writer.

The fact that the walls of the tract are noticeably heavier at the pyloric valve leads one to believe that there is probably a heavy ring of muscles there. However, in this insect it is not so. The thickness is due to the columnar structure of the epithelium of the hind-intestine, where it extends as a fold into the lumen of the mid-intestine (Plate II, Fig. 6). In fact, there are very few muscles of any kind right at the pyloric valve. The well developed muscle layers of the ileum appear just posterior to the valve.

The Malpighian tubules arise as invaginations of the hind-intestine, posterior to the pyloric valve. The hypodermal cells at the beginning of the tube are columnar, as are those forming the valve, but they gradually assume a more cuboid shape further out from their origin. The chitinous lining can be traced only for a short distance along the invagination forming the tubule. A few spines are also found along this invagination. A cross-section of a Malpighian tubule reveals that the epithelial cells in it are irregular in shape and have large nuclei (Plate II, Fig. 8).

The ileum has all the principal layers of tissue usually found in the hind-intestine. The tissues present, from within out, are:

(1) Intima.
(2) Epithelial layer.
(3) Basement membrane.

(4) Inner circular muscle layer.
(5) Longitudinal muscle layer.
(6) An outer circular muscle layer.

As mentioned above, the intima is provided with spines from the pyloric valve for a short distance into the ileum, approximately one-seventh of the total length of the ileum (Plate II, Fig. 9).

About half way from the pyloric valve to the colon, the waves or folds of the intima begin to appear as six more or less distinct projections. This becomes more and more pronounced, and by the time the colon is reached there are six well marked divisions (Plate II, Fig. 10).

The epithelial cells are more or less irregular in shape and vary in size to some extent, increasing slightly in size as they leave the pyloric valve region. By the time the colon is reached, these cells are comparatively large and more distinct.

The basement membrane is visible only in a few of the sections examined.

The inner circular muscle layer is well developed the entire length of the ileum.

The longitudinal muscle layer is well developed for a short distance posterior to the pyloric valve, then gradually dwindles to a few scattering muscles where the spines on the intima disappear. Approaching the colon, the longitudinal muscles develop into six well marked bundles (Plate II, Fig. 10).

The outer circular muscles are well developed also for the same short distance as the spines on the intima, but they diminish in number and finally disappear at the same level as the spines.

The colon is thinner walled than the ileum, and has the following layers of tissue from within out:

(1) Intima.
(2) Epithelial layer.
(3) Basement membrane.
(4) Circular muscles (inner).
(5) Longitudinal muscles.
(6) A sheath of connective tissue or "peritoneum" which encases the distal ends of the Malpighian tubules between it and the colon proper.

The intima in the colon is smooth. Its wave-like folds nearly fill the lumen at the anterior end of the colon, but recede somewhat toward the caudal extremity.

The epithelial cells are comparatively large and distinct. This layer of cells follows the intima closely.

The basement membrane is apparent in some sections.

The circular muscle layer is distinct, and forms the thin wall of the colon. It is composed of three layers of muscle cells.

The longitudinal muscles are present in six well developed bundles, each situated at the bottom of the division between the six folds of epithelium in intima.

The "peritoneum" or connective tissue is a delicate layer of thin nucleated cells surrounding the Malpighian tubules and the colon (Plate II, Fig. 11).

In some sections there appeared to be tiny canal-like openings leading from the caudal ends of the Malpighian tubules to the heavy chitin lining the tract at the junction of the colon and rectum. B. J. Landis was the first to call attention to this fact after making studies of the digestive tracts of several species of beetles having the tubules attached to the colon as they are in *P. pimelia*.

The rectum has much thicker walls than the colon (Plate II, Fig. 12). The layers of tissue present are:

(1) Intima.
(2) Epithelium.
(3) Basement membrane (occasionally apparent).
(4) Circular muscle.
(5) A very few strands of longitudinal muscle.

The intima is smooth and is in six folds or pads. If the tract happens to be full of food material, the folds are flattened out into six pads. These begin to extend farther out into the lumen as the caudal extremity is approached, and practically fill all the available space by the time the anus is reached. It is the opinion of the writer that these six pads, while similar to the rectal glands described by others, do not function as glands to any great extent, since their shape (including the structure of the cells) seems to vary directly with the presence or absence of food material in the tract. If they were distended when the tract is full of material, it would seem more likely that they might function as glands. However, they are largest when the tract is empty, and are reduced to a very flat layer when the rectum is full.

The cells of the hypodermal epithelium are slightly smaller and narrower than in the colon, and the cell walls are hard to distinguish.

The basement membrane can be demonstrated occasionally in this part of the tract.

The circular muscle layer is very well developed here. It is composed of six or seven layers of muscle fibers.

The longitudinal muscle layer is present as a very few scattered strands.

SUMMARY.

The alimentary tract of *Penthe pimelia*, Fabricius, is divided into three primary regions, namely: the fore-intestine, the mid-intestine, and the hind-intestine. These regions are more or less differentiated in themselves, showing the following parts:

Fore-intestine—The pharynx, oesophagus, and oesophageal valve.

Mid-intestine—Entirely stomach.

Hind-intestine—The pyloric valve, the Malpighian tubules, the ileum, the colon, the rectum.

The layers of tissue present in the different primary regions, from within out, are:

Fore-intestine—Intima, epithelium, longitudinal muscle, and circular muscle.

Mid-intestine—Gastric epithelium, circular muscle, and longitudinal muscle.

Hind-intestine—Intima, epithelium, basement membrane, inner circular muscle, longitudinal muscle, outer circular muscle, and "peritoneum."

The Malpighian tubules are six in number, and arise posterior to the pyloric valve at equal distances around the circumference of the tract. They are approximately twice as long as the body of the insect. One loop of each tubule goes forward along the mid-intestine for some distance (different tubules extend different distances) then go back to the colon, where they are attached to it by a thin membrane of connective tissue called the "peritoneum." Each tubule attaches separately and follows a zig-zag path caudad on the colon to the junction of this and the rectum, where it ends.

Histological examination of the ileum shows an interesting correlation between the presence of spines on the intima of this division for approximately the first one-seventh of its length, and the presence of well developed layers of longitudinal muscle and outer circular muscle, which also gradually disappear as the spines do. Sections posterior to this point show no spines, only a very few scattered longitudinal muscles, and no outer circular muscle layer.

REFERENCE.

Blatchley, W. S. The Coleoptera or Beetles Known to Occur in Indiana. Nature Pub. Co., Indianapolis, Indiana.

Boving and Craighead. 1931. Larvae of Coleoptera. Reprinted from Entomologica Americana, 11 (1–4).

Cecil, Rodney. 1930. The Alimentary Canal of Philaenus leucophthalmus L. Ohio Jour. Sci., 30 (2): 120–130.

Comstock, J. H. 1924. An Introduction to Entomology.

Davidson, R. H. 1931. The Alimentary Canal of Crioceris asparagi L. Ohio Jour. Sci., 31 (5): 396–405.

Fletcher, F. W. 1930. The Alimentary Canal of Phyllophaga gracilis, Burm. Ohio Jour. Sci., 30 (2): 109–119.

Kennedy, C. H. 1931. Lecture notes on the course "Morphology and Development of Insects," Ohio State Univ.

Miller, Warren C. 1931. The Alimentary Canal of Meracantha contracta, Beauv. (Tenebrionidae). Ohio Jour. Sci., 31 (3): 143–156.

Schaefer, Paul E. 1931. The Alimentary Canal of Sphaeroderus nitidicollis, Chev. Var. Schaumi, Chd. (Coleoptera). Ohio Jour. Sci., 31 (5): 406–415.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Dorsal view of alimentary canal.
Fig. 2. Cross-section of oesophagus.
Fig. 3. Longitudinal section of oesophageal valve.
Fig. 4. Cross-section of mid-intestine.
Fig. 5. Portion of cross-section through mid-intestine enlarged to show details.

PLATE II.

Fig. 6. Cross-section of pyloric valve showing Malpighian tubule attachment.
Fig. 7. Longitudinal section of pyloric valve showing spines and Malpighian tubule attachment.
Fig. 8. Cross-section of a Malpighian tubule.
Fig. 9. Cross-section of ileum just posterior to the pyloric valve showing outer circular muscle, longitudinal muscle, and spines.
Fig. 10. Cross-section of ileum near colon showing the development of six folds of epithelium and six bundles of longitudinal muscle.
Fig. 11. Cross-section of colon showing connective tissue surrounding the Malpighian tubules and the colon.
Fig. 12. Cross-section of rectum (when empty).

KEY TO ABBREVIATIONS.

B. MEM....Basement membrane.
COL.....Colon.
C. M.....Circular muscle.
C. M. I.....Inner circular muscle.
C. M. O....Outer circular muscle.
CR.....Crypt.
C. TIS.....Connective tissue or "peritoneum."
E. EPI.....Endodermal epithelium.
EPI.....Epithelium.
F. G.....Fore-gut.
H. EPI.....Hypodermal epithelium.
H. I.....Hind-intestine.
H. SEC.....Holocrine secretion.
IL.....Ileum.
INT.....Intima.
L. M.....Longitudinal muscle.
LU. MG....Lumen of mid-gut.
M. I.....Mid-intestine.
M. T.....Malpighian tubule.
M. T. ATT..Malpighian tubule attachment.
N.....Nucleus.
NID.....Nidus.
OES.....Oesophagus.
OES. V.....Oesophageal valve.
PH.....Pharynx.
P. MEM....Peritropic membrane.
P. V.....Pyloric valve.
REC.....Rectum.
SP.....Spines.

Penthe pimelia, Fabr.
Ross W. Brubaker

PLATE I.

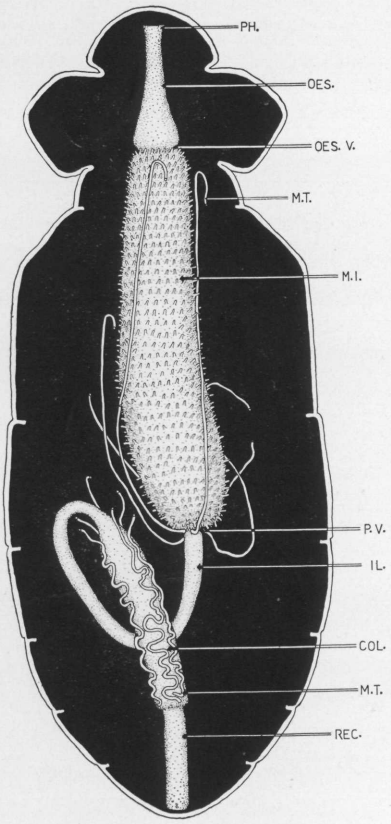
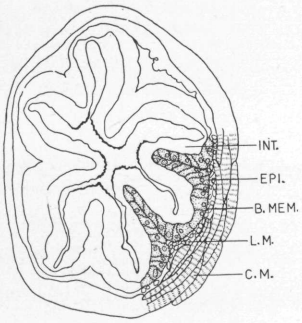


FIG. 1.



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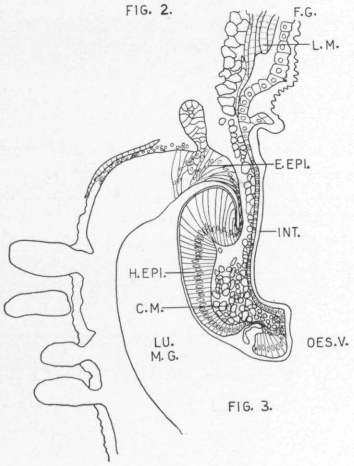

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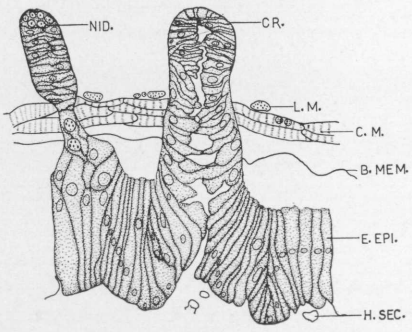

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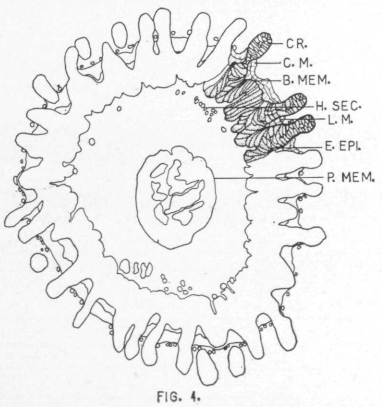

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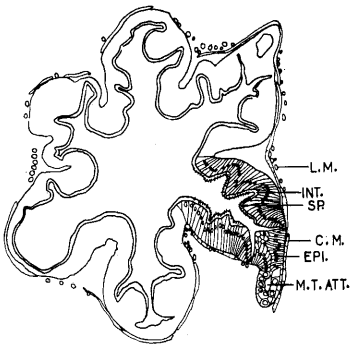

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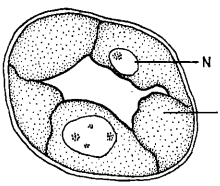

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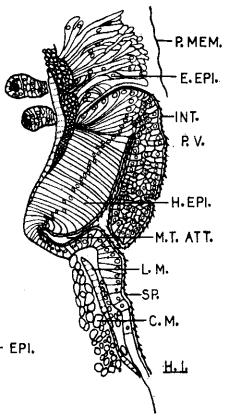

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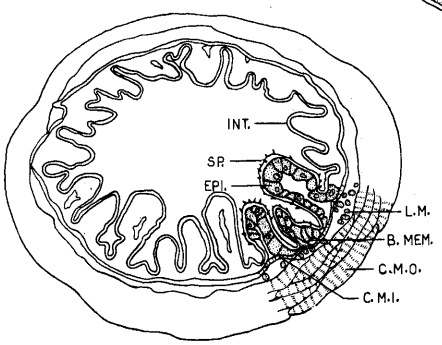

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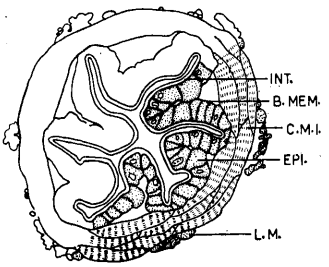
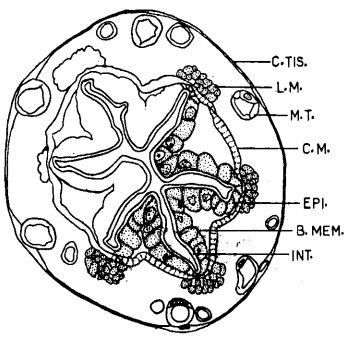


FIG. 10.



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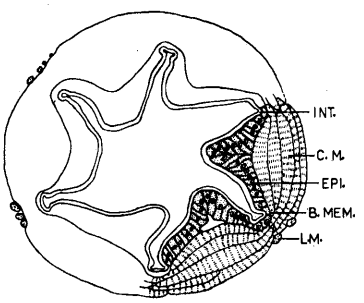

FIG. 12